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Extension services can promote pasture restoration: Evidence from Brazil's low carbon agriculture plan

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Innovation and improved practices in the livestock sector represent key opportunities to meet global climate goals. This paper provides evidence that extension services can promote pasture restoration in cattle ranching in Brazil. We use a randomized controlled trial implemented in the context of the ABC Cerrado (a large-scale program launched in 2014 aimed at fostering technology adoption through a combination of training and technical assistance) to examine the effects of different types of extension on agricultural practices, input use, and productivity. Providing technical assistance to previously trained producers promoted pasture restoration, induced farmers to use inputs more intensively, helped them to improve their management and soil conservation practices, and substantially increased revenues. A cost–benefit calculation indicates that US$1 invested in the ABC Cerrado program increased profits by US$1.08 to $1.45. Incorporating carbon savings amplifies this return considerably.

agricultural extension | technology adoption | cattle ranching

Significance

Livestock supply chains account for 14.5% of global greenhouse gases (GHG) emissions. There is a consensus that approaches that improve cattle productivity while enhancing carbon sequestration can contribute to the multiple goals of improving ranchers' livelihoods and mitigating climate change. Identifying policies that simultaneously increase productivity and sequestration is therefore critical to promote sustainable growth in the livestock sector. This paper documents the impact of training and technical assistance on pasture restoration and productivity in Brazil. We found that providing technical assistance to previously trained producers promoted pasture restoration, induced farmers to use more inputs, helped them improve their practices, and increased productivity and carbon sequestration. These findings highlight the importance of providing customized information to ranchers to help them sustainably intensify.

Innovation and improved practices in the agricultural sector represent key opportunities to meet global climate goals (1). Mitigating climate change through changes in the food system can involve reducing GHG emissions from production (2, 3), avoiding emissions from land-use change (4), and removing carbon from the atmosphere through carbon sequestration and storage in soils and vegetation (5).

Improvements in the livestock sector are a prominent example of how changes in food systems could jointly promote food production, economic prosperity, forest conservation, and climate change mitigation. Livestock supply chains contribute ∼14.5% of all human-caused greenhouse gas emissions and account for as much as one-third of total emissions in Latin America (6, 7). There is a broad consensus that approaches that improve cattle productivity while also enhancing carbon sequestration can contribute to the multiple goals of improving ranchers' livelihoods, mitigating climate change, and reducing pressure on forests (8–13). Modifying the behavior of livestock producers is critical for reaching these multiple goals.

There is widespread understanding among farmers that adopting good agricultural practices and improved pasture management can lead to higher productivity and higher income (14). However, multiple barriers can prevent adoption. Increasing the productivity of cattle ranching can be costly, and it may take many years to recuperate those costs (15). Labor shortages, financial constraints (e.g., poor access to credit), and limited access to technical extension services can also impede adoption (14, 16). The adoption of integrated crop–livestock systems by farmers in Brazil has been facilitated by access to rural credit (17) and to information, including extension services (18). Technical assistance is thought to be critical to the intensification of cattle systems in Brazil (especially for small- and medium-scale farmers) (19, 20). However, there is relatively little rigorous evidence on the role of extension services in promoting the adoption of productivity-enhancing, climate-smart livestock practices. There is also little evidence on the types of technologies, practices, and investments affected by the provision of extension.

This paper examines whether agricultural extension, in the form of training and technical assistance, can help to restore cattle pastures in Brazil. Brazil's pastureland has a very low average productivity, low stocking densities, and has shown no aggregate growth in productivity in roughly 20 y (21). Consequently, growth in beef production is often associated with deforestation to create new pastureland (22–24). Through the adoption of new agricultural practices and investments in technology and capital, pasture restoration could significantly increase Brazil's beef production while reducing deforestation (12, 25–27). For ranchers to adopt new agricultural practices and technologies, access to information is fundamental (28, 29). However, it is unclear whether information delivered by extension workers incentivizes farmers to adopt better

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practices and technologies. It is also unclear whether generic group training, one-on-one customized technical assistance, or combining the two is the most effective way for delivering information to ranchers (30–34).

We investigate these issues using data from a large-scale randomized controlled trial (RCT) implemented in the context of the ABC Cerrado program. This program, financed by the World Bank through a grant from the Forest Investment Program and implemented by the National Service of Rural Learning (Serviço Nacional de Aprendizagem Rural; hereafter SENAR), promoted the adoption of sustainable practices (e.g., restoration of pastures, cultivation of forests, use of no-till agriculture, and integration of crops, livestock, and forests) by rural producers in the Cerrado biome through a combination of training and technical assistance. The program's training component consisted of a 56-h course about one of the four practices promoted by the program, which was delivered centrally to groups of about 20 producers. The program's technical assistance component consisted, in addition to the training, of 24 visits (one visit per month) from field technicians to the producer's property, where they received one-on-one customized advice on the adoption of the practice in which they did the training. Producers only receive field technical assistance after first participating in the training. Since its creation, the ABC Cerrado program has trained 7,800 producers and offered technical assistance to 1,957 of these producers.

The RCT involved a group of producers who were interested in pasture restoration and were recruited to participate in the experiment. To be considered for the experiment, these producers had to complete a short application form providing basic demographic information and expressing their interest in participating either in just the training component or in both the training and technical assistance components. Producers were then randomly offered 1) training, 2) training plus technical assistance, or 3) no extension.

The analysis focuses on a set of producers interested in technical assistance, which can be divided into three groups: producers offered neither training nor technical assistance, producers who completed the training but were not offered the technical assistance, and producers who completed the training and were offered technical assistance. There are a total of 1,369 producers in these three groups. SENAR tried to collect data from random samples of 311 producers from each group and succeeded in collecting data from a random sample of 213 of the 663 ranchers offered neither training nor technical assistance (group T0, from hereon), 252 of the 395 ranchers who completed the training course but were not offered technical assistance (group T1, from hereon), and 276 ranchers of the 311 ranchers who completed the training and were offered technical assistance (group T2, from hereon) (Fig. 1). Data were collected from producers close to the time at which the technical assistance ended.

We analyzed these data to examine the short-term effects of the different types of extension (i.e., training alone and training plus technical assistance) on sustainable intensification. We first investigated the effects of extension on the access to technical assistance to understand whether the treatments increased the demand of farmers for technical assistance. We then investigated the effects of extension on three categories of outcomes, represented by seven variables (in italics), all of which are indicative of agricultural intensification: *pasture restoration* (share of property comprised of restored pastures), *rotational grazing* (indicator of whether the producer does rotational grazing), *good management practices* (index summing good management practices adopted by the producer), and *good conservation practices* (index summing good soil conservation practices adopted by the producer), *tractor use* (indicator of whether the producer used machines to prepare pastures), *pesticide use* (indicator of whether the producer uses pesticides for weed control), and *expenditures* (total expenditures of the property in R$).

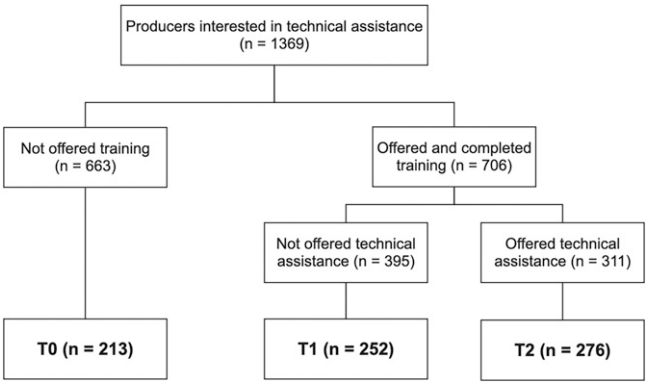

Fig. 1. Sample selection. There were 1,369 producers interested in technical assistance; 663 of these producers were randomly selected to be in the control group. We collected data from a sample of 213 of these 663 producers (group T0). Seven hundred and six were randomly selected to receive training and completed it. Of these producers, 311 were randomly selected to receive technical assistance, and 395 were randomly selected to not receive technical assistance. We collected data from 252 of the 395 ranchers not offered technical assistance (group T1) and 276 of the 311 producers offered technical assistance (group T2).

Results

Training alone did not improve any of the measured outcomes (Fig. 2), but technical assistance provided to previously trained producers caused statistically significant increases in all the measured outcomes (Fig. 3).

Effects of Training on Sustainable Intensification. We examined the effects of training on sustainable intensification by comparing the 252 producers who completed the training but who did not receive technical assistance (T1) with the 213 who were not offered training (T0) (Fig. 2).

Before the training, the differences in outcomes between ranchers in the groups T1 and T0 were mostly negative but were not statistically different from zero (Fig. 2*A*). Some indicators suggest producers who completed the training are negatively selected, while others indicate that those who completed the training are positively selected. A comparison of the ranchers' demographic characteristics reinforces this finding (*SI Appendix*, Table S1).

After the training was delivered, there were no significant differences in the proxies of practices, input use, or productivity between producers who completed the training (group T1) and the producers who were not offered the training (group T0) (Fig. 2*B* and *SI Appendix*, Table S4). The results are robust to changes in the specification (*SI Appendix*, Table S7), and there is no evidence of heterogeneous effects with respect to initial output (*SI Appendix*, Table S8). Coefficients for all variables were close to zero, and the confidence intervals were wide and straddled zero. However, there were differences between the two groups in their likelihood of receiving technical assistance other than the one offered through ABC Cerrado. Use of technical assistance in the T1 group was 0.15 to 0.18 SDs (6.4 percentage points [p.p.]) larger than in the T0 group, a difference that is

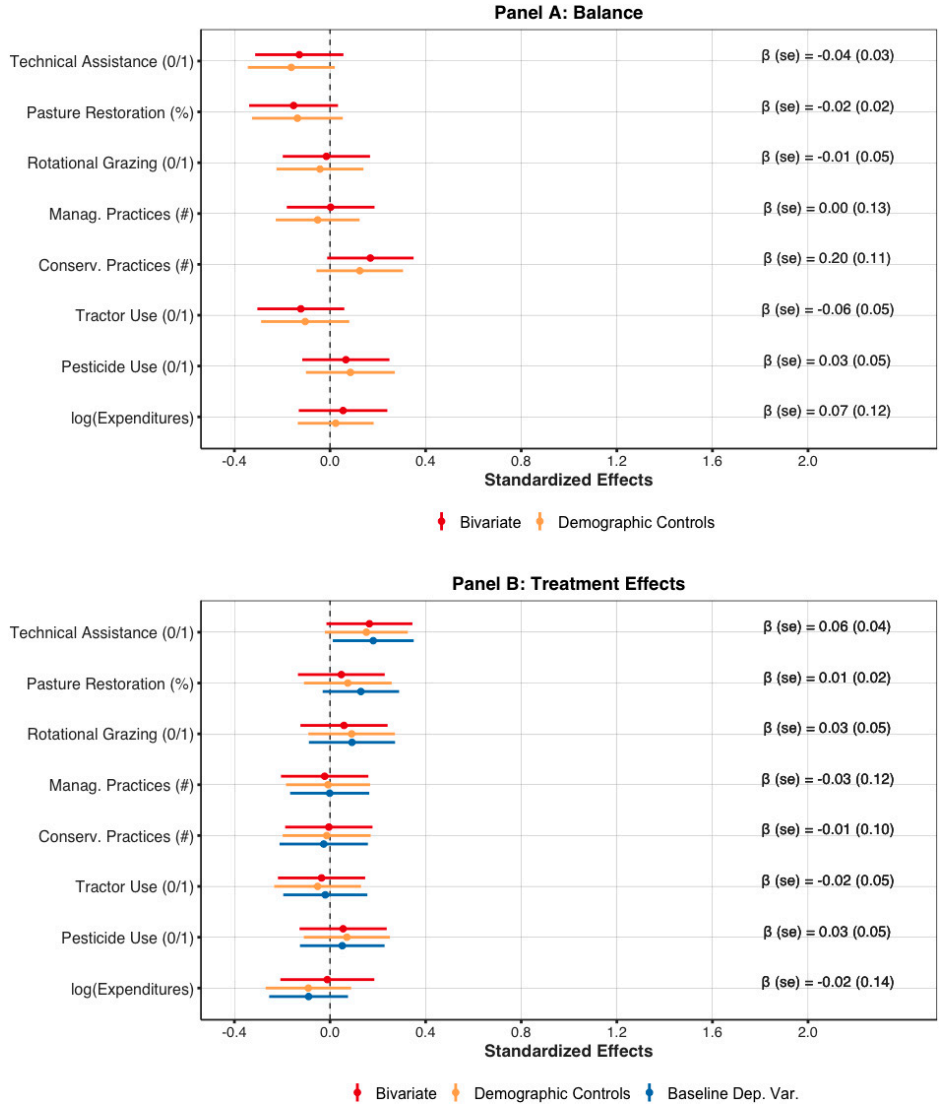

Fig. 2. Effects of training on the outcomes of interest. The dots denote the standardized mean differences between groups T1 and T0, and the lines denote their respective 95% confidence intervals. $\beta(se)$ reports the unconditional mean difference (and robust SEs) of the outcomes in their original scale. (*A*) Mean difference in the outcomes before training was delivered. (*B*) Mean difference after training was delivered. The colors denote the different specifications used: unconditional (red), conditional on predetermined demographic variables (yellow), and conditional on predetermined demographic variables and the baseline value of the dependent variable (blue). Manag., management; Conserv., conservation; Dep. Var., Technical Assistance (0/1), Pasture Restoration (% of the property), Rotational Grazing (0/1), Management Practices (# of practices), Conservation Practices (# of practices), Tractor Use (0/1), Pesticide Use (0/1), and Expenditures (log).

significant at the 10% level ($P = 0.073$). This indicates that training increased the demand for and/or access to technical assistance without influencing intensification and productivity.

Effects of Training and Technical Assistance on Sustainable Intensification. We examined the effects of training plus technical assistance on sustainable intensification by comparing the 276 ranchers who completed the training and received technical assistance (group T2) with the 252 ranchers who completed the training but were not offered technical assistance (group T1).

Before the training and technical assistance were delivered, there were no statistically significant differences in the eight variables between group T2 and group T1 (Fig. 3*A*). The differences in group means were close to zero, and the 95% confidence intervals were wide and straddled zero. Additional results reinforce this conclusion (*SI Appendix*, Table S2). This indicates that the groups were comparable before the interventions occurred.

Nevertheless, after training and technical assistance were delivered, statistically significant increases were observed in most of the outcomes examined (Fig. 2*B* and *SI Appendix*, Table S5). The results are robust to changes in the specification (*SI Appendix*, Table S7), and there is no evidence of heterogeneous effects (*SI Appendix*, Table S8). There are three main findings explained in detail below.

First, the intervention generated net increases in access to technical assistance. Access to technical assistance was 1.49 SDs higher (73 p.p., $P = 2.27 \times 10^{-91}$) in group T2 than in group T1. Second, producers who received training plus technical assistance were significantly more likely to adopt agricultural practices characteristic of intensification and to restore pastures. Group T2 restored 0.27 to 0.29 SDs (5.3 to 5.8% of their farmland or 11.5 to 12.6 ha; $P = 0.001$) more pastureland than group T1, was 0.20 to 0.21 SDs (10.0 to 10.5 p.p.; $P = 0.016$ to 0.020) more likely to use rotational grazing, had an index of good management practices 0.33 to 0.36 SDs higher (0.44 to 0.47 practices, $P = 3.30 \times 10^{-5}$), and had an index of conservation practices 0.24 to 0.25 SDs higher (0.25 to 0.27 practices, $P = 0.004$ to 0.006) than group T1. Third, producers

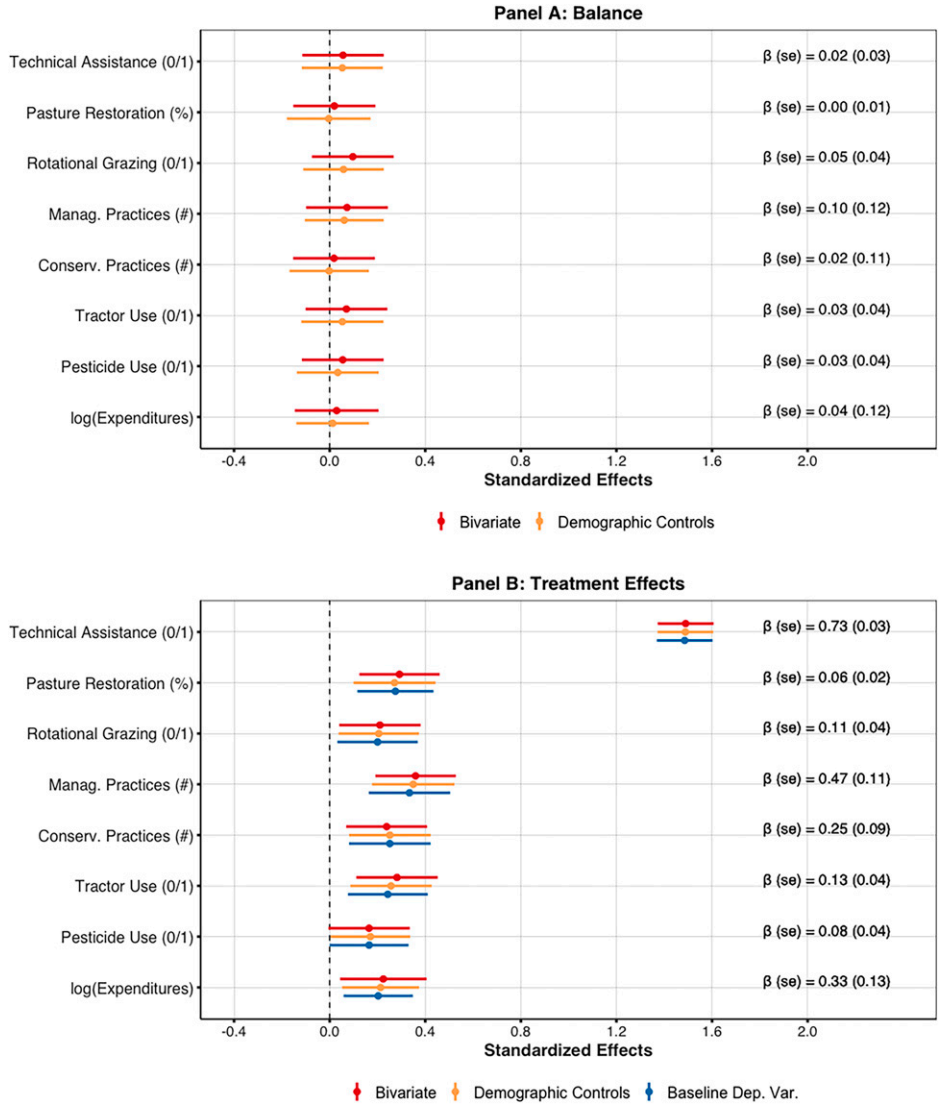

Fig. 3. Effects of training on the outcomes of interest. The dots denote the standardized mean differences between groups T2 and T1, and the lines denote their respective 95% confidence intervals. $\beta(se)$ reports the unconditional mean difference (and robust SEs) of the outcomes in their original scale. (*A*) Mean difference in the outcomes before technical assistance was delivered. (*B*) Mean difference after technical assistance was delivered. The colors denote different specifications used: unconditional (red), conditional on predetermined demographic variables (yellow), and conditional on predetermined demographic variables and the baseline value of the dependent variable (blue). Manag., management; Conserv., conservation; Dep. Var., Technical Assistance (0/1), Pasture Restoration (% of the property), Rotational Grazing (0/1), Management Practices (# of practices), Conservation Practices (# of practices), Tractor Use (0/1), Pesticide Use (0/1), and Expenditures (log).

who received training plus technical assistance were statistically significantly more likely to have higher inputs. Group T2 was 0.24 to 0.28 SDs (11.4 to 13.2 p.p., $P = 0.001$ to 0.004) more likely to use tractors and 0.16 to 0.17 SDs (8.2 to 8.4 p.p., $P = 0.045$ to 0.058) more likely to use pesticides than Group T1.

Profit maximization theory predicts that increases in expenditures are indicative of increases in marginal products and, hence, total factor productivity (TFP). Data on expenditures provide suggestive evidence that productivity grew because of the combination of training, technical assistance, and changes in practices and input use. The log of expenditures in group T2 was 0.20 to 0.22 SDs (34.6 to 38.9%, $P = 0.001$ to 0.015) larger than in group T1. Expenditures grew mostly due to increases in expenditures on modern inputs (*SI Appendix*, Table S9) and are driven by increases in expenditures per head of cattle (*SI Appendix*, Table S10). Comparable effects were observed for revenues even though revenues are not observed for 42.8% of the sample (*SI Appendix*, Table S11).

Under the hypothesis that the production function is Cobb–Douglas, the increase in TFP generated by technical assistance is the effect on expenditures multiplied by the share of land in production (about 0.20) (35, 36). Using the previous point estimates, this implies that TFP grew by 6.9 to 7.7% because of the provision of technical assistance to previously trained producers. This increase in productivity might reduce land use if the program is implemented at scale (37, 38), sparing land and decreasing emissions (9, 10, 11, 39).

Effects on Income and Cost Effectiveness. ABC Cerrado's cost was US$10.32 million: US$2.82 million for training, US$4.93 million for technical assistance, and US$2.57 million for administrative costs. This budget was used to train 5,843 producers and to provide technical assistance to 1,957 of those trained producers.

The program's returns come from the increases in profits (land rents). Rents are not observed in our data. However, it is possible to infer them combining data on expenditures with the

hypothesis that the relationship between output, land, and other inputs (capital, fertilizers, labor, etc.) can be approximated by a Cobb–Douglas function. This function has the property that the ratio of the income paid to the different factors of production is constant. In our context, this property implies that the ratio of rents to expenditures is constant, and, therefore, it is possible to infer the impact of the ABC Cerrado on rents by multiplying the program's impact on expenditures by the ratio of rents to expenditures (*SI Appendix*).

The mean ranch in the sample has expenditures of US$21,471 (USD$1 = BRL 4.01, 31 October 2019). Training did not increase revenues, but providing technical assistance to previously trained producers increased revenues by 38.80%. This implies that the ABC Cerrado increased expenditures by US$0 per ranch for farmers that received training and by US$8,344 per ranch for farmers that received training plus technical assistance. Multiplying these figures by the number of producers who received the interventions results in a growth of US$16.33 million in expenditures by the 7,800 producers involved in the program. Multiplying the growth in expenditures by the ratio of rents to expenditures (about 0.25), we find the ABC Cerrado generated a short run increase in land rents of about US$4.08 million.

The central question to determine the ABC Cerrado program's cost-effectiveness is how long is this increase in profits sustained? Our benchmark scenario assumes that the program's benefits disappear in 60 mo. Using a 7% discount rate, this implies a total increase in rents of US$11.21 million. This corresponds to US$1.08 per dollar invested considering administrative costs in the program's costs in the cost–benefit calculation and US$1.45 per dollar invested excluding them (see *SI Appendix* for a discussion of the sensitivity of these results).

Climate Consequences. Restoration of pasture that increases the productivity of beef and/or dairy production systems can have multiple potential climate consequences. Such restoration can alter global greenhouse gas emissions both by changing the intensity and aggregate amount of the direct emissions from production systems where the pasture is restored and by avoiding the need for, and resulting emissions from, producing the same quantity and type of food elsewhere. Key changes in direct emissions on the intervention farms include changes in enteric methane emissions from increased feed efficiency and changed livestock density, changes in emissions associated with the application of fertilizer, and changes in aggregate emissions caused by the increase in local output. Meanwhile, for the same level of production, production emissions and additional land use are both avoided elsewhere (12, 13, 40–42). The amount of carbon dioxide removed from the atmosphere by soils may also be affected by restoration. The soils of the restored pasture could see changed soil carbon dynamics as might soils in pasture systems displaced by changes in productivity. The project did not collect all the production, emissions, and carbon data needed to precisely estimate these effects. However, indirect methods using the data available do allow rough estimates (*SI Appendix*).

Climate emissions and avoided emissions. The ABC Cerrado interventions slightly increased direct emissions on the farms participating in the project. Using Cardoso et al. (43) combined with data on changed productivity and output from the project interventions, we estimated that production emissions declined by 169,000 tons of CO_2 equivalent per year ($tCO_2eq\ y^{-1}$) for existing levels of production on the intervention farms. However, levels of production increased on intervention farms, which increased emissions from the intervention farms by 220,000 $tCO_2eq\ y^{-1}$ but avoided 276,000 $tCO_2eq\ y^{-1}$ from production elsewhere, assuming that the production displaced had typical Cerrado emissions intensity. We also estimated reduced emissions from land occupation globally using carbon opportunity costs. Increased production on the intervention farms would avoid 886,000 $tCO_2eq\ y^{-1}$ in emissions from additional agricultural land using this approach. Summing changes in direct emissions and avoided emissions, the net effect of the program on emissions was a reduction of 1.11 million $tCO_2eq\ y^{-1}$. In line with previous findings, most of this effect is driven by the potential for avoided emissions from the use of additional agricultural land (12, 42, 44–46).

Carbon sequestration effects. Using an average from a range of estimates of the soil carbon sequestration from restored pastures provided by the EX-ACT tool (47), we estimated that the ABC Cerrado can be expected to have led to an increase of 81,700 $tCO_2eq\ y^{-1}$ of soil carbon sequestration. Rates of soil carbon sequestration in pasture systems are highly heterogeneous, uncertain, and subject to reversibility. For these reasons, soil carbon sequestration payments do not always garner a carbon price equal to those used for valuing mitigated emissions. However, due to the short time horizon of our economic analysis of the climate consequences of the program, we opt to include soil carbon sequestration gains.

The net effect of the program on greenhouse gases is 1.19 million $tCO_2eq\ y^{-1}$. Assuming a carbon price of US$40 tCO2eq, this implies that the program generated a climate benefit valued at US$47.6 million per year. This climate benefit alone exceeds the program's cost, implying that the ABC Cerrado would be cost-effective even if the benefits persist for just 1 y. This decrease in emissions has a present value of US$131 million or US$12.7 to 16.9 per dollar invested in the program (carbon price = US$40, discount rate = 7%, duration = 60 mo). There is extremely weak evidence that heterogeneity of the ABC Cerrado's effects with respect to the size of the operations reduce its environmental benefits. Neither the exclusion of carbon sequestration nor a set of considered sensitivity scenarios substantially influence the results (*SI Appendix*).

Discussion

Our analysis provides strong empirical evidence that customized, individual agricultural extension can provide farmers with the knowledge and skills needed to restore pastures and adopt new management practices that support sustainable intensification and increase income. While the economic and environmental benefits of agricultural intensification have been the subject of numerous studies (see refs. 12 and 25 for examples and ref. 48 for a recent review), there is substantially less research on the effectiveness of policies to induce sustainable intensification. We contribute to a growing literature demonstrating the importance of tailored extension (49–54) by providing evidence that on-site customized technical assistance is important to promote sustainable intensification among midsized ranchers in Brazil, inducing producers to adopt new technologies, improve management practices, and increase investments in modern inputs.

We do so in an important setting. Cattle ranching is responsible for 14.5% of global GHG emissions, Brazil is one of the world's largest cattle producers, and the midsized ranchers, such as the ones who participated in our experiment, are responsible for one third of Brazil's cattle production. Avoided deforestation policies help to promote cattle intensification (55), but the

extension services incorporated within programs like the ABC Cerrado are considered critical in supporting farmers in adopting best practices and increase productivity (56).

While our sample is not representative of the farmers in the country, our findings indicate that increasing the number of ranchers with access to technical assistance (currently at 20%) might be fundamental for the success of policies aimed at promoting the adoption of sustainable technologies in Brazil, such as the ABC Plan. It further indicates the limits of the policies focused on mitigating credit constraints that currently exist in the country (17).

The findings presented in this paper also have implications for the design of policies and programs focused on delivering information to farmers (28–30). There is considerable debate on the most effective policies to deliver information to producers (32–34). Organizations are continually trying to make traditional extension services more effective (31) by leveraging digital and information technologies at various stages of the extension provision chain (50). The ABC Cerrado was designed to shed light on which approaches are best suited to addressing the technological and management knowledge gaps on low-carbon practices and their long-term productive value. We show that complementing training with customized technical assistance to ensure assimilation and adoption of new concepts might be important to promote sustainable intensification.

Despite its importance, our design does not enable us to understand the importance of training. It is possible the effects of training are too small to be distinguished from zero. It is further possible that training alone does not work, but it is important to increase the level of knowledge and ensure that technical assistance works effectively. Moreover, our design is not suited to understand whether the barriers for accessing technical assistance before the ABC Cerrado were the availability, quality, or price of technical assistance provided by private companies. Furthermore, we lack information to understand the program's effects on physical production, limiting our ability to estimate its total effects on emissions. Finally, we do not know whether the benefits from technical assistance spillover to neighboring ranchers or are sustained through long periods of time. Understanding these questions is an important agenda for designing policies that promote sustainable intensification in cattle ranching in Brazil.

Materials and Methods

Data and Empirical Framework. The study was implemented by SENAR on behalf of Brazil's Ministry of Agriculture. The study was approved by the Project Monitoring Committee in accordance with SENAR's policies for research with human subjects. The study protocol required that producers that participated in the study sign a consent form that identified the purpose of the intervention and indicated that their information would be used for the purposes of evaluating the impact of the project.

The final data contain information on 741 ranchers (*SI Appendix*, Fig. S1). Producers were located in the states of Goiás, Maranhão, Mato Grosso do Sul, Minas Gerais, and Tocantins. The states Maranhão, Minas Gerais, and Tocantins concentrate most of the ranchers in the sample. The spatial distribution of groups T0, T1, and T2 is quite similar (*SI Appendix*, Fig. S2).

Each producer was interviewed twice. The first round of interviews occurred between July and October 2017, while the second round of interviews occurred between April and June 2019. The training occurred in the last trimester of 2017, and technical assistance was provided during the year of 2018. As such, the first round of interviews collected "pre-treatment" information, while the second collected "post-treatment" information.

In each round, the goal was to interview 311 producers from each group. However, enumerators could not find some of the ranchers either in the first or the second round of interviews. Attrition was highest in the T0 group (31.5%), intermediate in the T1 group (19.0%), and lowest in the T2 group (11.3%). We performed robustness checks to ensure that this differential attrition was not driving the results (*SI Appendix*, Tables S3, S6, and S7).

We estimated the effects of training alone using the following linear model:

$$y_i = \delta + \rho T1_i + \theta' X_i + \nu_i,\ i \in (T0,\ T1),$$

in which T1 is a dummy indicating whether the rancher belongs to group T1, X is a vector including predetermined controls and the baseline value of the dependent variable, and ν is an error term. The coefficient ρ identifies the effects of training. We use "pre-treatment" data to assess whether these ranchers had comparable outcomes before the intervention occurred (Fig. 2*A* and *SI Appendix*, Table S1).

We used the following analogous model to estimate the effects of providing technical assistance to previously trained producers:

$$y_i = \alpha + \beta T2_i + \gamma' X_i + \varepsilon_i,\ i \in (T1,\ T2),$$

in which y_i is one outcome of interest, T2 is a dummy indicating whether the rancher belongs to group T2, X_i is a vector including predetermined controls and the baseline value of the dependent variable, and ε_i is an error term. The coefficient β identifies the effects of training plus technical assistance. We use "pre-treatment" data to assess whether these ranchers had comparable outcomes before the intervention occurred (Fig. 3*A* and *SI Appendix*, Table S2).

Data Availability. Data have been deposited at https://dataverse.harvard.edu/dataverse/abc_cerrado. All other data are included in the article and/or *SI Appendix*.

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